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THE HAND AND THE MACHINE: A HYBRID APPROACH TO COMPLEX CONSTRUCTION IN A WORK OF SIR PETER COOK

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Abstract. This paper describes and provides a critique of the design and implementation of the “scoops” – a set of bespoke multifunctioning architectural free-form concrete elements that are a highlight of the new Soheil Abedian School of Architecture by the office of Sir Peter Cook and Gavin Robotham (CRAB). The development includes the transfer of analogue design processes into digital 3d modelling, which is then analysed and rationalized via an exchange with consultants and procurement contractors. The complexity of the concrete works necessitated the use of digital fabrication to make their implementation affordable and within time constraints, with said complexity creating a variety of challenges for many aspects of the entire delivery team. The 3d model played a critical role in communicating intent and accuracy at all stages. The use of site-based craftsmanship combined with computer aided design and fabrication overlapped to realize the project.

Keywords. In-situ concrete; 3d modelling; Rhinoceros; Peter Cook; digital fabrication.

1. Introduction

Architects and designers work in an age today where achieving formal complexity in their work is readily achievable via the spectrum of software platforms and modelling processes one can access in the studio environment. However taking complex formal qualities into the built world within budgetary constraints and quality standards is still often an experimental process and one imbued with risk. Pushing experimental work forward is critical for the discipline to advance (Beson, 2012), and through these instances, the procurement process is seen to evolve into more integrative means of collaboration and production between all parties in the building process (Kolarevic, 2011). Modelling software which

allows transference of information between disciplines – particularly across the chasm that often exists between parties focused upon design and those carrying out implementation – is key in enabling the integration required for novel and progressive advances in our spatial and material environment.

In December 2010, the office of Sir Peter Cook and Gavin Robotham, Cook Robotham Architecture Bureau Ltd (“CRAB Studio” London) won a two-stage, open competition to build a new faculty of architecture at Bond University, Gold Coast, Australia. The newest building on a campus originally designed by Arata Isozaki, the Soheil Abedian School of Architecture is a predominantly concrete building with bespoke glazing infill and a lightweight steel roof that will house 250 students upon completion in mid-2013, within a net area of 2500m².

The building is a culmination of Cook and Robotham’s position as both architects and as teachers at leading institutions globally. Informed by this academic experience, the project incorporates responses to many anecdotal criteria that are particular to architecture schools, as well as constructional and climatic objectives. The sociology of intimate groups within institutions, the value of casual overlay, and the importance of the non-curricula moments are all embedded in the project.¹ The primary physical embodiment of this attitude is featured in what is also of the most compelling aspects of the project: several four-storey tall in-situ concrete elements referred to by the designers as “scoops”.

Carrying out a variety of programmatic roles, the “scoops” support the roof, act as a buttress for lateral loads, accommodate vertical circulation along their perimeters, function as ventilation chimneys, create a venue for design critiques, and also carry light down into the central recesses of the building (Figure 1).

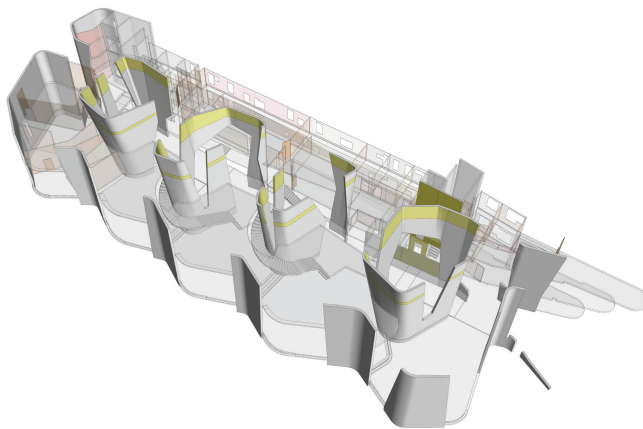


Figure 1. Isometric view showing the four “scoops” (CRAB).

Adding to this complexity is the formal resolution of the “scoops” themselves. These elements are customised in each instance although they share a common spatial and material quality in their totemic placement within the project’s organisation. The “scoops” curve in plan, splay in multiple directions in section, are punctuated with multiple voids and structural connections, and in two instances, support cantilevered concrete stairways.

2. Design Process: Competition Stage

As is typical of Peter Cook’s work, the project was initially developed using heuristic methods of sketching and physical modelling to develop and test the radical formal qualities of the project (Teyssot, 2010), and then was quickly developed through the use of McNeel Rhinoceros 3d (Rhino) and subsequently documented with Autodesk AutoCAD to hit immediate targets for Stage 1 of the competition phase. Conceptually, the “scoops” played a prominent role in how the project was conceived and represented in the early stage development of the project. Sketches by CRAB director Gavin Robotham indicate the interdependence of the “scoops” to anchor the scheme (Figure 2) and Peter Cook’s sketches for the competition presentation cast the “scoops” as the backdrop for key narrative scenarios in the building.



Figure 2. “Scoop” conceptual development sketch (CRAB).

3. Design Process: Development and Validation Stage

As noted, every element of the building was designed in the CRAB office in Rhino. Rhino was used to create a variety of instances and virtual prototypes of

the scoops in the context of the overall design, and beyond the office, the Rhino model proved to become an essential element of the procurement documentation.

To implement the “scoops” and other in-situ concrete elements of the building, the Rhino geometry was given to ARUP Brisbane as a DWG file in conjunction with PDF drawings. Similar to the process of engaging Bernhard Franken for the Kunsthaus Graz as noted by Kloft (2003), the structural engineering phase did not put any design pressure on the project and was able to support the designer’s intent fully, as the “scoops” are effectively normative load-bearing structures despite their geometric complexity. A principal challenge from a structural point of view was the accessibility of vibration equipment into the curving forms amongst the required density of reinforcing steel.

4. Implementation Process

The true challenges inherent in the concrete work became recognizable to the construction team only after the project works commenced. The project was carried out on a design/build contract, and as such, the contractor controlled and distributed all documentation including the 3d model in the form of a 3d PDF. The subcontract for the concrete work was awarded to a small but relatively experienced regionally-based firm. CRAB Studio had conceived that the concrete work would be cast using a combination of standard and custom-made steel formwork. However because very little of the geometry allowed for more than one pour, the contractor proposed site built plywood forms used in conjunction with limited reusable formwork. Within the first week of construction it was clear the complexity of the works would cause significant obstacles to achieve the necessary accuracy using conventional means of site carpentry. The contractor contacted international formwork supplier, PERI, to provide a possible solution. PERI Germany has previously implemented complex freeform geometry on the Mercedes Benz Museum, Stuttgart by UN Studio and projects by Santiago Calatrava, among others.

The 3d model proved to be the essential basis for communication of the exact intent and dimensionality of the desired building. Development of the formwork shop drawings was undertaken at PERI Germany and then transferred to PERI Brisbane for implementation locally, using the Rhino model as the key document.

5. Revised Process

PERI proposed a process used on previous freeform projects, namely, a system of “waffle slab” or notched plywood formwork with a curved plywood skin. This method, akin to developing cross-sectional prototypes, allows for the creation of

curved and raking surfaces on the pour side of the form, while maintaining a plumb and level face on the opposite side to which buttressing can be affixed during the pouring process. The notches in each perpendicular plywood rib enable site carpenters to easily and quickly jig the forms together with precision.

Initially, the PERI cost estimates for this method came in very high due to the number of customized forms. CRAB revisited the scoop geometry to introduce a greater degree of inter-changeability in the formwork geometry. This was handled rather intelligently to still achieve diversity and variation in the outcome, particularly by setting like formwork at different base angles in different scoops, for example.

The project was then re-evaluated and found to achieve the necessary cost reductions and thus a new strategy fixed into place for procurement. Each “scoop” in the project required 4 to 5 pours or lifts from top to bottom, with the average height between pours being 3.3m. In total, approximately 400 separate forms had to be installed with just under 50% of those forms being re-usable. As such, the customisation, tracking, and integration of the formwork needed to be highly detailed and organised. The forms themselves were fabricated from 18mm plywood and then surfaced with 6mm or 12mm plywood coated with polyurethane to achieve the required Class 1 finish.

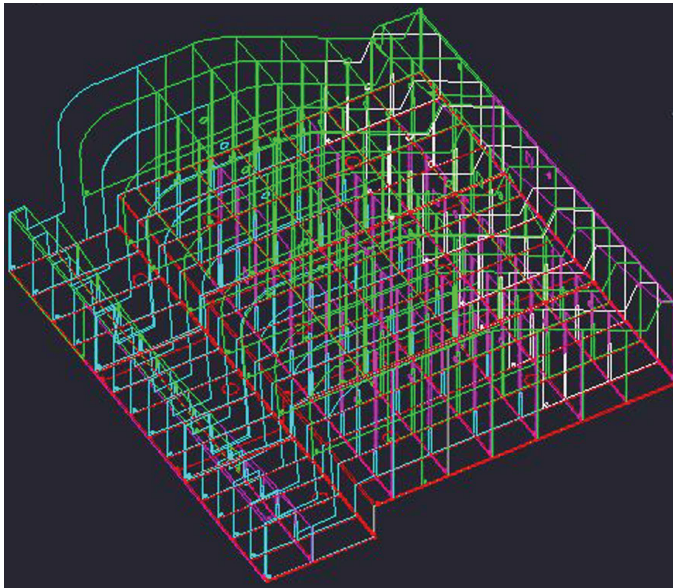


Figure 3. 3d Formwork shop drawing model (PERI).

PERI Germany developed the formwork shop drawings using AutoCAD 3d from CRAB's DWG file export. A manual technique requiring hundreds of instances of Boolean intersections were undertaken, and the ensuing drawings developed much like a drafting exercise as opposed to one of modelling. The need to establish a parametric model in this case, while perhaps obvious in retrospect, was not developed. It is important to point out the limited ability for collaboration to ensue between parties because of the construction contract.

Next in the process, PERI Germany sent to Brisbane a PDF A1 format shop drawing set detailing every element of custom formwork (again, more than 400 drawings, or approximately 100 per "scoop") and also a DWG file describing the waffle slab form as an un-nested, un-labelled 3d model view (Figure 3). The concrete contractor was responsible for unrolling and flattening all of the cut file geometry in AutoCAD and supplying it to the CNC fabrication subcontractor who then nested it, cut it, and sent it to site for assembly. This entire process of sorting and labelling the digital model was performed manually by CAD draftsmen for 2,400 plywood sheets.

6. Challenges and Results

A team of 35 formwork carpenters and labourers was required for on-site construction of the "scoops" and other concrete elements. While the concrete work was greatly aided by the supply of two-way gridded plywood formwork that was inherently self-jigging, many challenges still remained. Issues such as the varying radii, which required surfacing the formwork with different thicknesses of plywood in-situ, were one such challenge. Additionally, the PERI formwork indicated the location of tie-rods but the CNC milled formwork did not accommodate this in a conflict-free manner. Furthermore, the contingencies of on-site construction led to marginal but significant errors. Slight irregularities in the footings, for example, led to formwork being out of plumb, and thusly resulting in inaccurate connections to the next lift if they were not identified prior to the pour. Figures 4 and 5 shows a typical view of the construction site.

A surveying team assisted to verify locations of the formwork before all pours, and also to create as-built reference points after each pour to prepare for the next lift. The surveyor relied exclusively upon the CRAB 3d model, and similarly, subsequent trades in steel and glazing required these as-built drawings for their shop fabrication.

The engineering of the "scoops" required N-12 reinforcing steel at nominal 150mm and 300mm centres, encased by 40MPa concrete with 10mm aggregate and 100mm slump to ensure it wet enough to conform to the geometry without leaving voids or deformities. With all care taken, many irregularities, such as

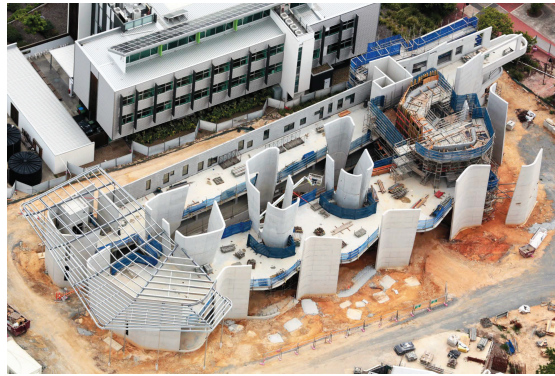


Figure 4. Construction process on site (ADCO).



Figure 5. Construction process on site (photo by Author).

lipping or small voids, did however eventuate and grinding/patching was required. Furthermore the interchange of plywood form surfaces mixed with proprietary steel forms where they were able to be used, meant a large range of resulting surface qualities that required mitigation.

At the inception, the concrete work was anticipated to unfold over a 6 month period. Instead, the works lasted nearly 12 months. While the prefabricated forms ameliorated the complexity of the project, the nature of the project was inherently difficult. While the building team proved up for the challenge, it was also a process that was entirely novel for most involved and thusly proved to be a very slow process and one which was costly. In the end, the work was very successful given the overall quality and powerful formal qualities of the architecture.

7. Conclusions

The conception and implementation of the complex concrete work in the form of the “scoops” at the Soheil Abedian School of Architecture represent a hybrid formation of both analogue and digital methodology, and offer a demonstration in the finished product of how these overlapping approaches integrate successfully (Figure 6). As a kind of spontaneous yet carefully controlled experiment, the team members involved were forced to innovate with the available digital tools and analogue methods available, and as previously suggested, one can identify areas in which the process could be improved or enhanced.

Compared to precedents for concrete construction in Australia, the work described here exceeded the experience of most members of the site team and required a tremendous leap in their pursuit of the required product. While PERI had previous off-shore experience with developing the requisite sophisticated formwork via CAD/CAM technology, the information flow was constrained, with no mechanism for feedback to influence subsequent rounds in the process. As such, the handcraft aspect of the process played an important role in closing the gap at the end of the digital workflow. Works of similar complexity such as Ito’s Fukuoka Island Park or Kakamigahara Crematorium (Sasaki, 2008) demonstrate difficulties resolved by modelling, digital fabrication, and site-intensive craftsmanship, but it is even in these instances the concrete work was not cast into formwork.



Figure 6. “Scoops” nearing completion – February 2013 (photos by author).

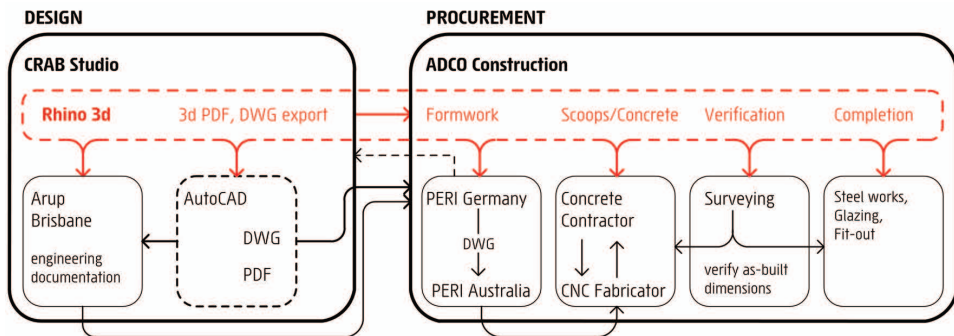


Figure 7. Workflow emanating from CRAB 3d model (by author).

Regarding information flow, this project offered a prime opportunity to apply an integrated project delivery method and the appropriate technological platform to support it. A standard design/build contract creates a segregated process, inherently bisecting the workflow into a “before and after” sequence relative to awarding the tender as indicated in Figure 7. Projects with elevated levels of complexity require an input and feedback loop between builder and designer to allow refinement and sharing of expertise. The Australian “Alliance” contract, or North American “Integrated Project Delivery,” would allow the type of non-standard protocol required (Williams et al., 2011). Even though the Rhino model allowed for information flow and for CRAB to maintain review of conflicts, the contractual apparatus used inhibited this review. CRAB made a very determined effort to share their intent via Rhino, but the platform does not support dynamic collaboration as would BIM platforms such as Digital Project (Beorkrem, 2013, pp. 11–12).

The formwork engineering and fabrication could have been improved and streamlined. The manual process of developing section profiles, labelling, and nesting of the individual plywood forms is a process which using Grasshopper, for example, could have been automated and compressed tremendously. Such a strategy would have easily integrated with CRAB’s preferred platform and allowed for parametric updating of all 2,400 cut files at the stage when the “scoop” geometry was rationalized. Combined with the appropriate contractual apparatus, CRAB could have occupied a central role with the “scoop” construction, offering an example of architect-as-master of this craft intensive process (Klinger, 2008). The contract applied to the project inhibited CRAB’s ability to communicate effectively once such problems and opportunities were identified. The engagement by the contractor of suitably experienced and skilled consultant could have aided the process by providing parametric maintenance of documentation. Few

consultancies, such as design to production or CASE, presently exist but they represent an emerging professional model for the discipline. In Australia, the firm AR-MA (Sydney) represents one such entity that could provide the required digital facilitation.

An exemplary outcome in complex concrete construction that all members of the process are rightfully proud, the “scoops” at the Soheil Abedian School of Architecture provide a valuable example of progress in the capacity of the Australian construction industry. The assessment and review of this process can hopefully serve to inform future endeavours of similar or advanced complexity, which are an imperative for industry growth. This project signals the need for tighter collaboration, effective contractual integration, and the need for appropriate digital technology to support efficacious delivery in a dynamic process with complex formal and spatial objectives.

Endnotes

1. <http://www.crab-studio.com/bond-university/> (07-02-2013)

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